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A Survey of Ancient Grain Milling Systems in the Mediterranean

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To David Peacock, a great connoisseur of mills and milling

Abstract

After thousands of years of exclusive use of saddle querns for grinding grain, a series of sophisticated mills appeared and developed in the Mediterranean during the second half of the first millennium BC and the beginning of the Common Era. These were the Olynthus mill, the rotary hand mill, the Iberian rotary pushing mill, the Morgantina mill, the Pompeian mill, the ring mill, the Delian mill, the watermill and the geared mill. Although studies of aspects of this subject have appeared in the past, these have usually been limited to one mill type or region. In this paper we intend to present an overview of the dynamics of innovation, continuity, influences and spread of these different milling systems.

Résumé

En région méditerranéenne, après de centaines d'années d'usage exclusif de meules à va-et-vient pour la mouture des céréales, dans le parcours de la deuxième moitié du premier millénaire avant J.-C. et le début de la notre ère, apparaissent et se développent une série de moulins plus sophistiqués: le moulin d'Olynthe, le moulin rotatif manuel, le moulin ibérique poussé, le moulin de type Morgantina, le moulin pompéienne, le moulin à anneau, le moulin délien, le moulin hydraulique et le moulin à engrenage.

Malgré les dernières années ont apparue des études à propos de quelques aspects du sujet, ils sont normalement limités à un type de moulin ou une région. Nous essayons dans ce travail de présenter un panorama des dynamiques d'innovation, de continuité, des influences et expansion de ces systèmes de mouture.

Keywords: Saddle querns, Olynthus mills, rotary hand mills, Iberian pushing mills, Pompeian donkey mills, ring mills, watermills, Mediterranean, Antiquity, Iron Age.

Mots-clés: meules à va-et-vient, moulins d'Olynthe, moulins rotatifs manuels, moulins ibériques poussés, moulins type Morgantina, moulins pompéiens, moulins annulaires, moulins hydrauliques, Méditerranée, Antiquité, Age du Fer.

1. INTRODUCTION

After thousands of years of use of to-and-fro saddle querns, a wave of innovations and inventions in the Mediterranean Basin revolutionised milling toward the middle of the 1st millennium BC. The aim of this paper is to offer a brief overview of these changes that took place throughout several centuries, drawing attention to the differences between the various regions of the Mediterranean.

We have encountered two major problems in this study. The first is that published data about querns and mills is not uniform. While some zones have been the object of studies in the last decades, others provide little or no information. Since the end of 19th century, several surveys of mills and milling have been published (BENNETT AND ELTON, 1899; LINDET, 1899 and

1900; STORCK AND TEAGUE, 1952; MORITZ, 1958; PEACOCK, 2013a). Regional studies, nonetheless, provide most of the data for these studies.

The main studies focusing on milling in the Eastern Mediterranean are R. Frankel's survey of the Olynthus mill (FRANKEL, 2003a; 2007; 2012) and L. Bombardieri's (2010) PhD thesis. As regards Greece there are the work of C. Runnels (1981; 1990); for Turkey there is the brief study of the Troad region (TAKAOGLU, 2008). For the Elephantine Island in Egypt there is the article by S. Wefers and F. Mangartz (2014). For the Central Mediterranean area there is practically no information with the exception of Seberta's general survey (1992) and Peacock's important article about the mills of Pompei (1989). Of great importance is White's work on the assemblage of mills from Morgantina (1963). North Africa suffers from the same situation as only a few papers are available (AKERRAZ A., AND LENOIR M., 2002; LEDUC, 2008 and 2011; Vos de *et alii*, 2011).

The situation in the Western Mediterranean is very different. Three recent PhD theses examine this area. The studies of M. Portillo (2006) and S. Longepierre (2011), both focusing on the Iron Age, are centred respectively on the Catalan coast and the south of France. T. Anderson in 2013 defended a thesis regarding the south of the Iberian Peninsula, from the Iron Age through the Roman Period, with a priority on the question of millstone quarries. The research carried out for many years by N. Alonso, in turn, is centred mainly on the origin, manufacture and use of rotary querns (ALONSO, 1996; 1999; 2002; ALONSO *et alii*, 2011; 2014 a; ALONSO AND PÉREZ, 2014). Furthermore, a collective work has very recently been published regarding mills and milling during the Iron Age in the Iberian Peninsula, including methodological and geographical studies submitted by various authors (ALONSO, 2014b).

Important works have been published about millstone quarry workings and trade by David Peacock (1980; 1986) and Renzulli *et alii*, (2002). Among these stand out the articles of O. Williams-Thorpe and R. S. Thorpe (1988; 1989; 1990; 1993) that included petrological analyses.

The second difficulty is the lack of conclusive dating for querns and millstones. Well-dated contexts are very unusual and the chronological ranges are often very wide and sometimes limited to only one global date for a site. In addition, it is known that many querns were reused and often found outside of original stratigraphical contexts. Once again, with the exception of a few isolated examples, the western Mediterranean provides the best-dated contexts.

This paper is organised in two sections. The first presents saddle querns and their use, a type that continues in use even today. This part also discusses some new and exceptional types. The second section examines the mills introduced in the 1st millennium BC. One of them is the Olynthus mill using the to-and-fro motion. Yet the main innovation is the introduction of the rotation motion in querns and mills, notably the Morgantina mills, Pompeian mills, ring mills and, finally, the watermills. In this paper we neither describe in detail each type of quern or mill nor review their subtypes, findings or archaeological contexts. We limit ourselves to the identification of the most important types in order to set in place the evolution of milling. Although we have cited a number of sites and dates, we have not attempted to include all of the published examples.

A table with a schema of the use of mill types presented in this paper is shown the Figure 1.

2. SADDLE QUERNS: CONTINUITY AND VARIATION

Mortars and saddle querns were the first tools used by humans for grinding a wide range of products. Current archaeological data points to a use of querns for grinding cereals in the Near East as early as the Upper Paleolithic, 10,000 years before cereal domestication (PIPERNO *et alii*, 2004). The tool generally called the "saddle quern" has been in use for thousands of years, and is used even today in some parts of the world. It even continued to be used long after more sophisticated grinding mechanisms were introduced. Meyers (2011, p. 246), for instance, has demonstrated that in Roman Galilee in the city of Sepphoris the Olynthus mill was in use, yet

in the mountain village of Nabratein only saddle querns were used. Ethnographic works, archaeological structures and iconography reveal the different ways saddle querns were operated (e.g. ALONSO, 2014a; BOMBARDIERI, 2010; PEACOCK, 2013a). They were driven, for the most part, on the floor, in a kneeling or sitting position, or standing on a clay structure or table.

We concur with David Peacock's view that saddle querns have been often grouped indiscriminately and not properly analysed (2013a, p. 12). Throughout their long life and wide geographical distribution, their lower and upper stones are, in fact, very heterogeneous. Currently, specialists are undertaking detailed research on the subject of prehistoric querns in several chronological periods and countries. Their work will certainly provide interesting data that will enable more accurate future classifications.

Nevertheless, this is not the goal of the present work and we will mainly point to a few exceptional types that appeared during the first centuries of the first millennium BC.

2.1. The Assyrian type (Figure 2a1 and 2a2)

This is a type of saddle quern found mainly in Mesopotamia and less frequently in the Near East. Its main characteristic is the presence of a groove on the surface of the upper stone, which is used to lodge a lever. In fact, the Assyrian mill is the first and the earliest lever mill known in the Mediterranean area (BOMBARDIERI, 2010, p.78-85) (Figures 1g).

The upper stones of this type are basically rectangular with rounded corners and a flat grinding surface (length 30-40 cm, width 20-30 cm, height 5-10 cm). The regular shaped groove carved into the upper surface is parallel to the longest sides of the grindstone. The groove is most often off-centred (type A) or, in a few cases, centred on a smaller and ellipsoidal upper stone (type B) (BOMBARDIERI, 2010, p.78-79, fig. 92). The lower stones of this type are rectangular, flat or slightly concave. The best studied assemblage is that of Tell Barri (Syria) (BOMBARDIERI, 2008).

The earliest Assyrian mills date from the 9th century BC. The latest were in use until at least the 5th-4th century. As noted previously, they were spread mainly throughout northern Mesopotamia and the Syrian Levant. Furthermore, they are recorded mainly in major Assyrian cities (e.g. Tell Barri, Tell Ahmar, in Syria, and Nimrud, in Iraq). In the Southern Levant, examples are published from Tell Qasile and Tell Tannim (Israel). Unfortunately the dating of these mills is not precise (AVSHALON *et alii*, 2004) (Figure 2a.1). L. Bombardieri suggests that the Olynthus mill developed as a result of contacts between the Assyrian mill (with the innovative lever) and the hand grip hopper saddle quern (with the innovative hopper) (BOMBARDIERI, 2005, p.499). Nevertheless, this second type could be, in some cases, a simplified version of the Olynthus mill (see below) (FRANKEL, 2003, p.8).

Grooved handstones have been also reported in other very different contexts during the Iron Age in the Loire Valley (GEORGES *et alii*, in this volume) and, according to Storck and Teague (1952, p. 72-73, fig. 36), on the Island of Delos.

2.2. The Archaic Greek type (Figure 2b)

Although this mill type does not present any characteristic or innovative function, we present it because it is the first Greek quern known in the Western Mediterranean. It first appeared in the 6th century BC. It is a "standard" shaped quern recorded mainly since the Bronze Age in the East, and not until the Iron Age in the West (it could be Peacock's type 4, 2013, p. 14-16). Its lower stones are either oval or elliptical. The western examples are for the most part rectangular (grinding tables) and often associated with sub-rectangular or, more commonly, eye-shaped upper stones. These "eye-shaped" upper stones are found at several Greek settlements between 6th and 4th BC bearing strong Greek colonial influence, such as Ullastret

(Catalonia) or Lattara (France) (Figures 1b and 2b). Examples have also been recovered in the cargo of the 6th century shipwreck of Cala Sant Vicenç (Catalonia) (VIVAR, 2008). Their use is similar to that of other saddle-querns. The extremities of the "eye-type" upper stone facilitates the grip during grinding.

2.3. Hand-grips and Ribbed types (Figures 2c-g)

Another variation is the upper stone with two hand-grips (Figures 1c-f). This type was in use between the 5th and 1st century BC. In some cases the upper stones are oval with two lateral horizontal grips placed on the upper surface of the grindstone (Figures 1c and 2c).

An unusual type is found in Minorca (Balearic Islands) during Iron Age. It has a longitudinal rib on the top of the upper stone (Figures 1d and 2d) and its average length is 51 cm (FERRER, 2011, p. 180).

Another unusual shaped saddle quern with hand-grips appears at several sites in the Near East such as Horvat 'Ein Koveshim (AVASHALOM *et alii*, 2004) and Sarepta (PRITCHARD, 1978, p. 88, fig. 73). Its provenance suggests a Phoenician origin (Figures 1e and 2e). The side facing the operator of the stone is rounded both in plan and in section. It originally tapered down to a point making the complete stone a section of a sphere. The fragment from Horvat 'Ein Koveshim is 46 cm wide and 13 cm high at its highest point in the centre. Parallel to the edge of the stone are two grooves serving as hand-grips. The flat lower grinding surface is dressed and parallel to the rounded end of the stone (AVSHALOM *et alii*, 2004). The Sarepta example is presumably from the Iron Age (1200-586 BC) while the Horvat 'Ein Kovshim mill is probably from the Hellenistic Period (332-37 BC). Another recent find is dated to the Persian Period (586-332 BC).

Finally, a special subtype of hand-grip saddle-quern must be highlighted because it probably had an important role in the following innovations (see below). This sub-type has both hand-grips and a hopper (Figures 1f, 2f and 2g). Poorly dated examples are known from the Greek sites of Priene (Turkey) and Delos (Cicladic Islands). They are elliptical and very similar to the upper stone of a saddle quern. Other examples are rectangular. One rectangular model with hand-grips, hopper, and dressed grinding surface was found in Thera (Figure 2g) (GAERTRINGEN AND WILSKI, 1904, fig. 193). Another unpublished example, also rectangular with hand-grips and a hopper, was discovered during the rescue excavations in Rhodes. It is now on display in the archaeological exhibition of the Palace of the Grand Master. All four are found in and around the southern Aegean Sea (Frankel 2003a, Fig.11)

3. MILLING INNOVATIONS FROM THE MIDDLE OF THE 1ST MILLENNIUM BC

From the middle of the 1st millennium BC the diversity of milling systems and devices increased immensely. The introduction of hoppers, levers, dressing of the grinding surfaces, and, most notably, the rotatory motion, are some of the aspects of the progress in milling that took place. We will present the most important mill types and their characteristics.

3.1. To-and-fro motion: the Olynthus mill (Figure 4b)

The standard Olynthus mill is a lever mill. The exception is a subtype with hand-grips (see above). The upper stone is either rectangular or square, with a rectangular cutting or slit on its upper side that slopes down to join the grinding surface (Figure 1h and 4b). In the standard rectangular type found in the Eastern Mediterranean, there are grooves on two opposite sides of the rim usually on the short sides opposite the end of the slit (Figure 4b.1-2 and 4-5), but sometimes in the middle of the long sides. A small hole at times filled with lead is often either directly below one or both of the grooves on the side of the stone. This feature is appears not to be present on models found in the western Mediterranean (Figure 4b.3).

When the Olynthus mills first drew the attention of archaeologists, their use was far from clear. Some were published without description and others were thought to be windows. W. M. Flinders Petrie (1888) was the first to recognise that this device was a grinding tool and K. Kourouniotes (1917) was the first to correctly explain its function, basing his argument on reliefs on the 3rd century BC Megarian bowl (Figure 3d).

In his reconstruction of the standard Eastern type, a long wooden rod was attached to the upper stone in the two grooves. The rod was probably secured with wire attached with lead in the small holes to the stone, or in other cases perhaps using cord tied to a peg inserted into the hole. The rod served as a lever. The upper stone was fixed close to one end of the rod. The short end of the rod was attached to a vertical pin on a table, while the long end served as a handle. However, at an excavation at Gamla in Israel an Olynthus mill was found *in situ* in the corner of a room showing in this case that the rod was inserted into a niche in the wall. There is, in fact, a passage in Talmudic literature that clearly refers to both methods (pin or a niche in the wall) (FRANKEL, 2003a: 6 figs. 3, 5, 6)

The size of the standard upper stone is 40-55 cm in length, 15-20 cm in width and 5-10 cm in thickness. The lower stones are rectangular and measure 45-60 cm in length, 30-45 cm in width and 5-7 cm in thickness (CURTIS, 2001, p. 281, note 45).

Characteristic of the Olynthus mill are the furrows that appear on the lower surface of the upper stone and on the upper surface of the lower stone. These dressings come in a variety of patterns consisting mainly of parallel lines, herringbone patterns or a combination of both (FRANKEL, 2003a, figs. 7 and 8) and mark a significant innovation in grinding efficiency. They increased the grinding surface, facilitated a better grip of the kernels, and enabled the grains to be cut rather than crushed, thereby yielding larger pieces of bran that facilitated the subsequent separation of the bran (CURTIS, 2001, p.281).

Different types of Olynthus mills and their geographical distribution were established by Frankel (2003a). The device varied according to the shape of the upper stone and its hopper, the method of attaching of lever, and its dressing patterns.

There is no doubt that the Olynthus mill originated in the eastern Mediterranean. Yet what remains unclear is if it was invented on the Greek mainland or in Anatolia. The earliest archaeological examples date to 425-400 BC in Athens. At Olynthus itself the examples also date to the 5th century BC.

The hand-grip saddle-querns described above could be an intermediate type, between the simple saddle quern and the Olynthus mill. The examples from Thera and Rhodes, rectangular with hopper handgrips, could also be a portable type of Olynthus mill. Unfortunately, these examples are not accurately dated.

It has been long recognised that the Olynthus mill was the mill of Classical Greece. It is common in Israel and Ptolemaic Egypt (4th c. - 1st c. BC), at least in Upper Egypt (J.-P. Brun, personal communication), and appears in the western Mediterranean in the 4th century BC. The fact that this type is found in large numbers in Sicily, in Magna Graecia in southern Italy, and was spread in Provence in southern France, all Greek colonies, suggests that it spread westward by Greek colonists. However it did not penetrate into regions such as Iberian Peninsula where the rotary quern already existed. Greek colonisation, however, cannot alone explain the aspects of the distribution pattern of the Olynthus mill. Other factors must be sought for the examples found in North Africa and in the Italian Alps (FRANKEL, 2003a).

It was still in use until the 2nd century BC in western Mediterranean, for example in *Lattara* (PY 1992) or in the *oppidum* of Saint-Estève (Brun 1984, p.11), and much later in the East, for instance at least until first-second century AD in Greece (*Isthmia* or Athenian Agora, RUNNELS, 1981, 127) and Egypt (*Mons Porphyrites*, PEACOCK, 2007, fig. 9.8; *Didymoi*, BRUN, 2011, p.245). Furthermore, it was present in Israel until the 6th century AD (for instance, *Tamra*, TEPPER, 2007, or *Khirbat al-Karak*, DELOUGAZ AND HAINES, 1960, p. 22, 10). It is clear that the hand mill of the New Testament and of the early Talmudic literature, the Mishnah and Tosephta, is the Olynthus Mill"

The use of Olynthus mills offers various advantages when compared to saddle querns. First, it allowed the miller to stand upright while working, in a position more comfortable than working with a saddle quern. Besides, the operator did not need to press down on the upper stone. Secondly, the hopper accommodated larger quantities of grain and it was not necessary to stop as often to add more kernels. The increase in size of both stones also served to raise the grinding capacity (CURTIS, 2001, p. 284-286).

3.2. The rotary motion: hand and pushing mills

The use of rotary motion already existed in Eastern Mediterranean in the Early Bronze Age either on the vertical plane, as in the case of the wheel, and on a horizontal plane as in the case of the potter's wheel. In the middle of the 1st millennium BC, new devices of different form and function applying rotary motion were invented both in the western and eastern Mediterranean. In the west the horizontal motion served for grinding grain as seen by the rotary quern and the Iberian pushing mill. In the east the vertical motion is evidenced by rotary olive rollers, the "edge runner" or *trapetum* for crushing olives (FRANKEL, 1993; 1999, p. 68-73).

One of the advantages of the rotary motion, as opposed to the reciprocal motion, was that it followed only one direction and therefore was continuous and uninterrupted. This enabled the use of animal traction and later of that of water, wind and machinery.

3.2.1. The rotary hand mill (Figure 4a)

After saddle querns, the rotary hand mill or quern is the milling system that remained in use for the longest period of time. The first examples are from the middle of the 1st millennium BC. Today they are still present in some rural zones in the Mediterranean Basin (e.g. Turkey, Greece, Magreb) (ALONSO, 2014a).

A rotary hand mill or rotary quern consists of two circular stones one above the other, both between 25-50 cm in diameter. The upper stone rotates on the fixed lower stone with a continuous circular motion. It has been suggested that in some cases the movement was semi-rotary. The height of the upper stones can be up to 25 cm and for the lower stones up to 35 cm. In the Mediterranean region the most common upper stone is cylindrical, i.e., it has vertical sides (PY, 1992; PORTILLO, 2006; ANDERSON, 2013, 45; ALONSO AND PÉREZ, 2014; LONGEPIERRE, 2012 and 2014) (Figure 1i and Figure 4a).

In the centre of the upper stone there is usually a hole, "the eye", that served both as a hub that rotated around a spindle inserted in the centre of the lower stone and as a hopper through which the grain was poured. To be an effective hub the hole had to be small; yet to be an effective hopper it had to be large. This problem was often solved by a device known as a rynd, a perforated metal or wooden bridge attached to the upper stone. This feature permitted the union of the two stones and allowed the flow of grains through the eye of the upper stone. Noteworthy are examples of Chinese rotary hand mills with no "eye" (FRANKEL, 2012: 117-118).

Ethnographical studies show that the rotary hand mill was usually operated at floor level by a seated person with one leg bent and the other outstretched (ALONSO, 2014).

The morphology and fittings of rotary hand mills evolved through time. In the western Mediterranean during the Iron Age (6th-2nd c. BC) their morphological diversity is significant, especially in Iberian culture, where the manufacture of mills seems to be a local activity. Most of the rock outcrops serving to make these mills are found near the settlements. There are, nonetheless, examples of more distant millstone trade (ALONSO *et alii*, 2011; ANDERSON, 2014; LONGEPIERRE, 2014, p.297-298). Unfortunately, no quern quarry dating to the Iberian Iron Age has as yet been identified on the Iberian Peninsula.

In northern France and England the most common rotary querns have flat grinding surfaces and a very thick upper stone with large and deep hoppers. These are often called Beehive querns and are usually associated with the La Tene Celtic culture (Figure 4a.6). Childe (1943) was the first to point out that examples from the Iberian Peninsula were quite different. This author associated them with Cato's *molae hispaniensis* (*De Agricultura*, X, 4). In southern France both types are known since the 3rd century BC at sites such as *Lattara* (Figure 4a.5) and during the 2nd-1st century BC at Thermes and Chastelard (PY, 1992; LONGEPIERRE, 2014). The rotary hand mills from Israel usually have a vertical projection on the centre of the lower stone and the handle hole is either in a horizontal lug or vertical or both (Figure 4a.6). They are, however, dated to later periods.

The typology of rotary hand mills is usually based on the inclination of the grinding surface and handle fittings, although there is still little agreement on a common typology. In the Iberian Peninsula during the Iron Age there are, in many cases, two handles, although in the 4th-3th century BC some examples with a single handle are documented. Handles can be fitted in ear-like lugs (fashioned directly from the rock) or inserted in a cutting (mostly vertical slit, "inverted keyhole" or "dove-tail" and "L" shaped slots) or a hole. Lugs with vertical holes, slits cuttings or "inverted keyhole" seem to be characteristic of the Iberian Culture (PORTILLO, 2006; ANDERSON, 2013, 47; ALONSO AND PÉREZ, 2014, 245-246) (Figure 4a.3).

Regarding Roman rotary hand mills from southern Spain, T. J. Anderson observes that handle cuttings changed from two opposite lateral cuttings for a crosspiece to a single hole on the upper surface. Besides, in the Roman period special means of assembling and tenting were introduced. These including rynds and other fittings on the upper surface (ANDERSON, 2013, p. 44-51) (Figure 4a.8-9). In the south of France, S. Longepierre identifies a typological transition at *circa* 250 BC, from early Iberian types to other, more standardised types with rynds (LONGEPIERRE, 2014, p. 296-297).

Different types of pecked grinding surfaces from the 5th century BC, and furrow patterns from the 3rd century BC, have been recorded in Iberian Iron Age mills (LEPERAUX-COUTURIER, 2014; ALONSO AND PÉREZ, 2014, p.246-247, fig. 6).

In the Eastern Mediterranean, the earliest rotary hand mills date to Roman times and present smaller diameters. In Greece, for instance, examples measure a maximum of 38 cm (RUNNELS, 1990, 151; WILLIAMS-THORPE AND THORPE, 1993, p. 270).

The rotary hand mill is probably an Iberian cultural innovation, invented in the north-east of the Iberian Peninsula and South of France during the end of the 6th or the beginning of 5th century BC. The largest assemblages of these early rotary querns are found in the north-western area of the Mediterranean Basin, at the sites of Els Vilars d'Arbeca, Turó de Ca n'Olivé, Alorda Park (Catalonia) or Pech Maho (France) (ALONSO, 1997, 1999, 2002; ÉQUIPE ALORDA PARK, 2002; GAILLEDROT AND SOLIER, 2004, p.416-417; PORTILLO, 2006; LONGEPIERRE, 2014) (Figure 4a.1-2).

The small fragment found in a Punic context in Byrsa (Tunisia) suggesting the existence of rotary hand mills in North Africa at the end of the 6th century BC, is ambiguous (MOREL, 2001, p. 242-243, fig.1) It is devoid of any characteristic element such as an eye or handle cutting.

Moreover, the first devices of this type in Central Mediterranean Basin are documented in Sicily in the 3rd century BC (WHITE, 1963; PEACOCK, 1989) and in Italy and North Africa in the 2nd century BC. They are associated with Morgantina mills and Olynthus Mills (e.g. WHITE, 1963, MOREL 1969, p. 480; LANCEL 1982, p. 93-103) (Figure 4a.4). No rotary hand mill, not even a fragment, has been brought to light in Punic sites during the 4th century BC, whereas Morgantina mills are well documented.

D. Peacock claimed that "it is worth nothing that assemblages of Punic or Greek mills in Sicily lack rotary querns: the sites of Agrigento, Akrai and Motya are dominated by Olynthus mills and while Pompeian/Morgantina types are present occasionally, rotary querns are absent (personal observation). This suggests that they were not used to any extent in the central

Mediterranean between the 6th and 2nd century BC” (PEACOCK, 2013a, p.55). Likewise, rotary hand mills are rare in Morocco and Sardinia, where they are even imported from Agde (France) (WILLIAMS-THORPE, 1988, p.260; WILLIAMS-THORPE AND THORPE, 1989, p. 90 and 110).

However, the rotary hand mill spread rapidly during 5th-4th century in the eastern area of the Iberian Peninsula and in southern Gaul (until the Rhône valley) (ALONSO AND PÉREZ, 2014). During 3rd-2nd century, it spread to the rest of Iberian Peninsula (see regional approaches by various authors in ALONSO, 2014b), to Provence, in association with the Olynthus mill, and to northern Gaul (JACCOTTEY *et alii*, 2013; LONGEPIERRE, 2012 and 2014) and also to the north of the Alps (WEFERS 2011).

The spread of Roman influence prompted the expansion of rotary hand mills to the rest of Mediterranean Basin: during the 1st c. BC to Greece (RUNNELS, 1990, p.153) and not before the 1st century AD to Israel. At Masada, the defenders of the Jewish fortress in 73 AD used Olynthus mills while the Roman conquerors used rotary hand mills. The Roman conquerors then discarded the Olynthus mills and recycled them to pave the floors (NETZER, 1991, p. 290-291). In fact, in this zone, the rotary quern only replaced the Olynthus mill completely in the Byzantine period (FRANKEL, 2003a, 18).

3.2.2. The Iberian rotary pushing mill (Figure 5a)

In the Iberian Peninsula there is evidence of a particularly large rotary mill, the Iberian rotary pushing mill, that we suggest should be regarded as a separate type.

The innovation of rotary motion permitted the increase of grinding capacity resulting in a higher yield because, for the first time, the upper and the lower stones had equal grinding surfaces. In addition, the rotary motion allowed the manufacture of bigger mills that could not be operated by hand. Indeed, in the Iberian Peninsula, since the first appearance of rotary motion, and mainly during the 4th and 3rd century, we observe two phenomena, the existence of very large rotary mills and the use of "mill podia" or very thick lower stones (ALONSO *et alii*, in press; ALONSO AND PÉREZ, 2014).

Regarding rotary mills, the analysis of the relationship between the diameter and the height of the Iberian upper stones (ALONSO AND PÉREZ, 2014) reveals the presence of two groups:

(a) a type with a small upper stone with a diameter less than 50 cm and a height less than 25 cm. Most examples of this type correspond to rotary querns described above.

(b) a type with large upper stone corresponding to the Iberian rotary pushing mill. This type has three sub-groups: (b.1) with a diameter equal or larger than 50 cm; (b.2) with a diameter lower than 50 cm but a height larger than 25 cm (Figure 5a.1); and (b.3) a very large upper stone with a diameter surpassing 50 cm and a height more than 25 cm (Figure 5a.2); (ALONSO AND PÉREZ, 2014, p. 243, figure 3).

The upper stones of the Iberian rotary pushing mills are similar in form to those of the rotary querns and have varied handle systems (vertical straight fittings, handles fashioned directly from the rock and with fittings). These large mills are too heavy to be driven by hand.

Furthermore, in 14 of the Iberian sites dating from the 4th and 3rd centuries, 25 of these mills are associated with podia. In some cases, these are directly associated with complete rotary mills (upper and lower stones) (Figure 5 a.3 and a.4). There are also a few examples in the Ebro Valley and in the Mancha region. Most of the podia are cylindrical, erected with stone and clay. The best preserved have a trough with a drain to gather the flour. Their diameters range between 50 to 110 cm and their height varies between 28 and 60 cm, with an average at 43 cm. Although the position of most of these podia permits a peripheral rotary motion (Figure 5a.3), some do not (Figure 5a.4) (ALONSO *et alii*, in press; ALONSO AND PÉREZ, 2014, p. 247-249, fig. 7 and 8).

In certain cases a very thick lower stone also served to elevate the mill (ALONSO *et alii* in press; ALONSO AND PÉREZ, 2014, p. 243-245). It is also possible that there were wooden

supports (such as tables) at sites without podia that could have served as bases for these large mills.

There are five cases of complete mills associated with podia. The total height (base plus mill) and the weight of the millstones suggest they were driven by means of a horizontal lever by one or two people. For this period we can discard the use of animal traction, mainly due to the lack of space around the mill. These mills are very different from the more common rotary hand driven querns, and since they are characteristic of the Iberian culture, we propose they be called the Iberian rotary pushing mill.

3.2.3. The bi-conical: Morgantina and Pompeian mills (Figure 5b)

The classical hour-glass shaped Pompeian mill is the most emblematic mill of the Roman world. It is known as a Donkey Mill in Greek Latin and Hebrew but it should be noted that in the Greek version of Diocletian's Edict on Prices a horse mill is also mentioned (LAUFFER, 1971: no.52a, pp. 147 and 257). It is well-known in the urban bakeries of Pompeii, Herculaneum and Ostia (PEACOCK, 1989), as well as in the provinces (JACCOTTEY AND LONGEPIERRE, 2011; DE VOS *et alii*, 2011; ANDERSON, 2013, p. 60-61; PEACOCK AND WILLIAMS, 2014; WEFERS AND MANGARTZ, 2014) (Figures 5b.7 and b.8). It consists of a conical lower stone and a bi-conical upper stone joined by the spindle set in a hole on the top of the lower stone. The upper hopper is the receptacle for the grain and the lower is the grinding surface. Two opposite square sockets with two small holes are located at the girth of the upper stone. The many iconographic representations of this mill (e.g. Figure 3c) clearly reveal how the wooden rig was fitted to the donkey.

In Hebrew the two stones of the donkey mill had names that are different from those of the hand mill. An edict regarding the distance of the location of this mill from a neighbour's wall (to avoid unwanted damage) records that "...the distance from the wall of the lower stone שכב *shekhev* literally "that lies down"] of a hand mill [in this case an Olynthian mill] must be three [hand breadths] which is four from the upper stone רכב *rekhev* literally "rider"] and of a donkey mill three from the lower stone איצטרובל *itstrubal* fruit of fir trees similar in Greek] which is four from the upper קלת *qelet*] (Tosephta Baba Bathra 1,2). In Latin texts there is apparently only one reference to upper and lower millstones (Digesta XXXIII 7.18.5) recording that the *meta* is the lower stone and the *catillus* the upper. Although it is not specifically stated, the reference is clearly to a donkey mill. Just as the Hebrew *itstrubal* (cone of the fir tree) is similar in form to the lower stone of the donkey mill, so the *meta* is similar in form to the conical marker used in Roman stadiums. In the same passage (7.18.22) the donkey of the donkey mill "*asinam molendarium*" is mentioned.

The forerunner of the classical Pompeian mill is the Morgantina mill. D. White's (1963, p. 205) analysis of the assemblage of Morgantina (Sicily) established the main differences between the Morgantina and Pompeian types (Figure 5b). An important contrast is that the former is much smaller. At Pompeii the average height of the upper stone (*catillus*) is 70 cm and that of the lower stone (*meta*) 60 cm, whereas the largest *catillus* at Morgantina is only 36 cm high and the highest *meta* less than 50 cm.

D. Peacock and D. Williams (2014) describe another small biconical Pompeian mill found in the Near East, that is more cylindrical in shape than the classic form and usually about 35 cm high. Its date is unknown.

In addition to size, the Morgantina mill's *catillus* differs in shape. The upper cone serving as a hopper is always much smaller than the lower cone (Figure 5 b.1, b.2 and b.3). Furthermore, the lateral lugs or sockets are also very different. The Pompeian mill's sockets are small relative to the height of the *catillus* and recessed into the wall at the girth. The Morgantina sockets, at the base of the mill instead of the girth, take the form of large sockets that dominate much of the external section. They have openings at their top (Figure 5 b.1, b.2 and b.3).

In addition, some of the Pompeian *catillus* had a band wrapped around their girth and the Pompeian *meta* had a rounded top, while the Morgantina *catillus* lacked all traces of such a central band and the top of its *meta* was invariably flat.

Nearly all of the Pompeian mills in Israel are very similar to those from Pompeii. Yet they do have a feature common to the Morgantina mill. They have two opposite small holes on the rim between the two main sockets. These are clearly for an additional frame or fitting that is possibly mentioned in the Talmud¹ (WHITE, 1963, p. 203, note 33; FRANKEL, 2003b, p. 47). In certain cases these *catilli* bear these holes on the upper and lower rims, indicating that the upper stone was reversible (Figure 5 b.5).

Elsewhere there are other variants that are without doubt connected in some way to the classical Pompeian and the Morgantina mills. There is an upper stone from Ecija (Seville), that instead of bearing two sockets has four perforated lugs (SÁEZ FERNÁNDEZ, 1987: p. 112) and in the British Museum there is an example from Hamworthy, but that could be modern (BENNET AND ELTON, 1898, p. 183; SMITH, 1931, fig. 11) (Figure 5b.3 and b.4). It has two similar protrusions with holes, a very small upper cone and two small holes on the rim, features that are similar to those of the Morgantina mill and the Pompeian mills in Israel. Similar mills were found in France (LINDET, 1900, fig. 16). All these unfortunately are undated.

The Pompeian mill was almost certainly animal-driven, as demonstrated in a number of reliefs depicting bakeries (e.g. Figure 3c, cf. also ZIMMER, 1982), although in some cases they could have been driven by men as was the Morgantina mill. In this sense they are both pushing mills. The two earliest Morgantina mills were found in the Sec ship wreck (Mallorca) dated to the 4th century BC (ARRIBAS, 1987). The analyses undertaken by O. Williams-Thorpe and R.S. Thorpe (1990, p.133) reveal that at least one of them came from the Mulargia quarry district in Sardinia. These authors speculate that this mill could have been loaded on the ship at Carthage. The connection between the quarries from Sardinia and Carthage is well known in the Roman period (PEACOCK, 1989, p.50). Therefore, although bi-conical mills are found neither in Sardinia nor in the Carthage area until the 3rd-2nd century BC (LANCEL, 1982, p.93), we can assume that they were known there earlier, during the 4th century. Also, in Sicily, although the Morgantina mills date to the 3rd century at the site of Motya (destroyed in 397 BC), a lava lower stone from Pantelleria (Sicily) was found. Although from a superficial deposit, this strongly suggests a date at least from the early 4th century BC (PEACOCK, 2013, p. 90).

Some of the earliest examples of classical Pompeian mills in France (1st c. BC) seem to be associated with mining activities rather than bakeries. There are a great number distributed throughout the Narbonne province (JACOTTEY AND LONGEPIERRE, 2011; LONGEPIERRE, 2012). Yet recent research suggests that this type of mill was not widely adopted in Roman *Hispania*, as not more than a dozen are known throughout the whole peninsula (ANDERSON, 2013, p. 60-61). In the Eastern Mediterranean, Pompeian Mills were widespread in the Roman period and one example has been published from the Hellenistic period from Mount Gerizim in Israel (MAGEN 1993: fig. 36.1).

3.2.4. The ring mill (Figure 6a)

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-----שאלן עשויות אלא לחזק הסדור" "צנורות התופסות את הרחיים מלמעלה

"The pipes { צנורות } that hold the mill from above -----only serve to strengthen the arrangement" (Tosephta: Kelim Baba Metzia 2-15)

During the Late Iberian period in the south of the Iberian Peninsula, in the 2nd century BC, a new type of rotary mill appears. It is described in detail by T. J. Anderson (2013, p. 56-57). It consists of a roughly cylindrical, ring-shaped upper stone with a "D" section and a lower stone with a steep grinding surface, with an elongated neck topped by a circular or square spindle hole. Upper stones have vertical slits, "L-shaped" or "inverted keyhole" lateral cuttings (BERROCAL, 2007, p.292) for their driving fittings. This type differs from the Iberian pushing mill because of the shape of both upper and lower stone. It is not known in the Eastern Iberian regions.

Although these mills are reported at a number of Iberian Iron Age sites in the south of Spain, only two sites have examples with secure chronological contexts: Cerro de la Cruz and Castrejón de Capote (QUESADA *et alii*, 2014; BERROCAL, 1989, p. 258; 284, fig. 26.1). At the first site a few mills are associated at times with charred cereals and cylindrical podia built of stone and earth. They measure about 110 cm in diameter and 25 cm high. The Iberian ring mills from Cerro de la Cruz have a size of 51-58 cm in diameter. The height of the complete mill is 59 cm (QUESADA *et alii*, 2014) (Figure 6a.1 and a.2).

Roman ring mills are similar to the Iberian ring mills, but larger. The upper stones have a ring shape, with a D-section, straight vertical edges and lateral cuttings, L-shaped rectangular or "dove-tail" incisions. The lower stone is conical or bell-shaped, with a square spindle hole (Figure 1m and Figure 6a) (ANDERSON, 2013, p. 58-59; PEACOCK, 2013a, p. 94-95).

T. J. Anderson has pointed out that, when devoid of context, it is not always possible to differentiate the Roman ring-mills from the Iron Age models (ANDERSON *et alii*, 2011, p.154; 2013, p.58). However, the lower stone usually develops a marked platform ("sombbrero" shape) (PEACOCK, 2013a, p.95).

Peacock and Williams (2014, p.101) describe some mills from Jordan as ring mills and Wefers and Mangartz (2014, fig. 7) call some mills from Elephantine Egypt that fit the term "pseudo-Pompeian type millstones".

The ring mill is characteristic of southern Spain and northern Africa. In fact, it is also labelled as the *Volubilis* type due to the many examples documented at this settlement in Morocco (ETIENNE, 1960; AKERRAZ AND LENOIR, 1981-82, p. 71-73, pl. VI-VII) (Figure 6a.2). At *Volubilis* this type of mill is related to the olive oil industry. Hence Frankel (1993; 1999, p. 72-75) suggested that this is Columella's *mola olearia* and he labelled it the horizontal oil mill. However, several researchers suggest a "multifunctional" use both for crushing olives and also for milling cereals (AKERRAZ AND LENOIR, 2002; PEÑA, 2010, p. 574, 576, 750). A study of the *Volubilis* mills suggests that volcanic basalt ring mills, without dressing, were for grinding grain, whereas the shell-rich sandstone ring mills, dressed with furrows, were for grinding olives (AKERRAZ AND LENOIR, 2002). Another more recent interpretation has the basalt ring-mills directly associated with the *pistrinae* (bakeries) (LEDUC, 2008 and 2011). They date largely from the 2nd century AD.

3.2.5. The segmented Delian mill (Figure 6b)

The Delian mill is an exceptional segmented mill, identified for the first time at the Island of Delos (DEONNA, 1938) (Figure 6c.1). Both upper and lower stone are made of several small pieces of lava segments bound with iron cramps set in lead. New excavations during the 1980s permitted to observe the disposition of the parts of one of these mills dated to 69 AD (BRUNET, 1997, p. 29). According to Peacock, the reason for segmentation is always simple: the rock with superior grinding properties could only be obtained in small pieces. Regarding the Delian mills, the source of the lava could not provide large blocks suitable for monolithic millstones (PEACOCK, 2013b, p.154). Peacock proposes three types (2013b, p.154-155). The reconstruction of their use is not simple and attempts have been advanced by Stock and Teague (1952, p.79, fig. 40) and Brunet (1997, p.30, fig. 2 and 3) (Figure 6c.2-3).

Examples of segmented mills are known in Nekuomanteion (Western Greece) dated to the Hellenistic period, as well as Karanis, Clysma and Mons Porphyrites, Badia (Egypt) (PEACOCK, 2013a, p. 97; 2013b, p.162) and Megara Hyblaea (Sicily) (Chaigneau, in this volume). The mill from Nekuomanteion is the earliest example dated by Runnels (1981, p. 134) to 234-167 BC. It is interesting to note that segmented Delian mills were in use until the 4th century AD at, for example, Badia (Egypt) (PEACOCK, 2013a, p. 97).

4. WATERMILLS

Information about several watermills dating to the first centuries AD has been compiled recently by J.-P. Brun (in press)². These types of installations are known in Athens (PARSONS, 1936; SPAIN, 1987), Rome (WIKANDER, 1979; SCHIOLER AND WIKANDER, 1983; WILSON 2003), North Africa (WILSON, 1995), France (LEVEAU, 1996; BRUN AND BORRANI, 1998; JACCOTTEY AND LABEAUNE 2010; BRUN, in press; BRUN ET ALII, in press; JACCOTTEY AND ROLLIER, in press), Switzerland (CASTELLA 1994) and England (SPAIN, 1985; 2008; HOWARD 2011; WILSON 2010; SIMPSON, 1976; WIKANDER, 1985). Apparently only two might be dated to the first century BC: Mailhac in France (HARFOUCHE et alii 2005) and Bolle in Jutland (STEENBERG, 1979). It must be noted that there is doubt as to if this last example is a watermill (e.g. WIKANDER, 2000, p. 394).

The archaeological evidence contributes little to the knowledge of the technical details of these mills. Our knowledge of the early models is mostly from pre-industrial evidence and written sources.

Preindustrial evidence indicates that there were two main types. The type with the horizontal water wheel is often called the Norse or Greek mill (WILSON, 1960, note especially the different types of water wheels, *ibid* fig. 2 and the different types of "penstocks", *ibid* fig.1, 3, 4, 5). The second model is equipped with a vertical wheel (REYNOLDS, 1983) and is often called the Vitruvian mill (Figures 7a.1 and a.2). In both types the millstones are usually similar to those of the rotary hand mill but larger. They are driven from below by a spindle that passes through the eye of the lower stone and attached to the *catillus* either by holes in the top surface (the "Avenches" type, CASTELLA 1994) or by a rynd lodged the eye of the lower surface. In the case of horizontal wheels, the spindle is connected directly to the water wheel. In the case of vertical wheels, the spindle that turns the millstones is turned by a geared mechanism.

As regards the early history of watermills, the two main questions are where was the watermill invented and what is the relationship between the two types. Until recently the earliest sources were in Latin and dated to the 1st century AD: Pliny [*HN* XVIII, 28.97] and Vitruvius [*De Architectura* X, 5.2, with a detailed description of the vertical mill], a reference in Hebrew from the Roman Period (Tosephta Shabat 1,28), and in Greek: Strabo (*Rerum Geographicum* X, ii 556) from the 1st century BC and a poem by Antipater (for Greek original and English translation, MORITZ, 1958, p.131). Yet it is not clear whether Antipater is from Thessaloniki (1st c. BC - 1st c. AD) or Sidon (130 BC). Avitsur (1960) suggested the second option and as the pre-industrial watermills in Israel were equipped with horizontal wheels, he presumed them to be the early type and that the watermill originated in the Levant. His suggestions were not accepted (see for example SMITH, 1985). However, a recent reassessment of earlier Greek texts that have only survived in their Arabic translations (LEWIS, 1997; AD *et alii*, 2005, p.167; FRANKEL, 2007 217), and the discovery of water-mills in Israel with Pompeian type Millstones (AD 2005 *et alii*; FRANKEL 2007), provide additional support for Avitsur's suggestion that the watermill originated in the Eastern Mediterranean at a date earlier than previously thought.

5. GEARED MILLS

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We express our gratitude to J.-P.Brun for this unpublished article.

Millstones very similar in size and form to those that equipped watermills have been found in places where there are no streams or rivers that could have served to power them (MORITZ, 1958 122-130). Their driving mechanisms have been reconstructed in two different ways. The first, though geared like the Vitruvian mill, is driven by man. The second has been reconstructed as driven by donkey or horse (MORITZ, 1958: fig. 14; FRANKEL, 2003b, p. 49, 50) (Figure 7 b.1 and b.2). Many of this type have been reported at Saalburg in Germany on the border of the Roman Empire and probably operated by Roman soldiers. An example was also found at Fishbourne in England (CUNLIFFE, 1971, p. 153, no. 9, fig. 7, 9).

6. CONCLUSION; MILLING TRADITIONS AND INFLUENCES IN MILLING DURING THE FIRST MILLENNIUM BC

We have shown how from the middle of the first millennium BC the diversity of milling systems in the Mediterranean basin clearly increased after thousands of years of use of the same method with roughly the same type of quern. Two main new milling systems were the Olynthus mill and the rotary mill. The rotary mill in the form of a quern could be driven by hand or, in its larger format, by a man or animal (Iberian rotary pushing mill, Morgantina/Pompeian mills and ring mill). Later mills were driven by water, wind and finally by machinery. It is significant that vertical rotary olive crushers were also invented at about the same time.

The Olynthus mill originated in the East, in Greece or in Anatolia, and the rotary quern and the Iberian pushing rotary mill in the West, probably in the northeastern and eastern region of the Iberian Peninsula. Finally, the Morgantina mill originated in the central Mediterranean area. To understand the significance of the typological differentiations, the emphasis must be placed not only on chronological sequences but on the interrelated effects of cultural continuity and regional diversity (FRANKEL, 1999, p. 176).

The eastern mill was brought to the west and the western to the east. These exchanges took place at different rates and with different results. The Olynthus mill arrived in the west rapidly during the 4th century BC, brought almost certainly by Greek settlers. In the west it was used in limited areas and only for a short periods probably because it could not compete with the rotary quern (Figure 8a).

The rotary hand mill did not appear in the east until later. It arrived in Greece in the 1st century BC and in Israel in the 1st c century AD. It was almost certainly introduced to both areas by Roman legions, probably because it was transportable. After a long time, it finally supplanted the Olynthus mill. Although it was invented much later, the Pompeian donkey mill moved eastwards earlier. In Israel an example has been reported from the Hellenistic period and this type was widespread during the Roman period. As a result, in the west the rotary quern (and the Iberian rotary pushing mill) arrived before the Pompeian mill while the opposite was the case in the east.

One characteristic of ancient technical cultures was conservatism. The Olynthus mill, for example, was still in use in the Levant until the Byzantine period long after the arrival of the rotary quern. Similarly, in the Iberian Peninsula rotary querns and Iberian rotary pushing mills sufficed. Therefore, the other types of Mediterranean mills were not adopted. It is interesting to note in this regard the absence within the Iberian world of Morgantina mills and Olynthus mills. This contrasts with the situation in the central Mediterranean area or the south of France (Figure 8b). At present, only one Olynthus mill has been found in the whole Iberian Peninsula. Yet it is not in an indigenous context, but at the Greek colony of Rhodé (Roses, Catalonia) (GENÍS, 1986, p. 113). It was only later, during the Imperial Roman period, that the Pompeian mill was introduced into the cities and *villae*. The Pompeian mill, however, never

became as widespread as the rotary hand and pushing mills (SÁEZ, 1987, 105-112; ANDERSON, 2013, p. 60-61).

There might be a broad cultural or more narrow cultural-identity explanation for the Greek and Iberian reticence to mills other than the Olynthus mill and rotary mills. Another example is the Etruscan civilisation that was highly influenced by the Greek and Eastern worlds but appears, nevertheless, to have been completely closed to the Olynthus mill (DAL RI, 1994, p. 60). The primary reason for cultural continuity and regional diversity is a subjective human factor, clearly related to the isolation of one human group from its neighbour. This will be most marked where there are ethnic differences, particularly where these find expression in differences in language and religion and in political borders. These factors are usually also accompanied by local traditions and techniques (FRANKEL, 1999, p.176).

All the evidence combines to focus on the central Mediterranean as the point of origin of Pompeian mills. D. Peacock (2013, p. 92) suggests that their origin could be at Mulargia in Sardinia. For this reason the site came to be known as *Molaria* in the Roman period. Another candidate is Sicily. It is very likely that the Pompeian mill evolved from the Morgantina mill. The appearance of the Morgantina was almost certainly a result of the convergence of the knowledge of the Iberian rotary quern with two handles from the west, with that of the Olynthus mill in the east. The rotary movement and the two sockets deriving from the Iberian quern and the large hopper from the Olynthus mill. In addition, the awareness of the existence of two such different types made it psychologically easier to overcome the inherent conservatism of ancient technologies and to develop a new type (Frankel, 2003a, p. 19). However, the first rotary querns known in the Central Mediterranean date to the 3rd century BC while the earliest Morgantina mills are from the 4th century BC. Apparently only the knowledge of the existence of the rotary quern reached the region earlier because of the contacts between Iberian culture and Punic cultures. This could be another example of "conceptual transfer" (Frankel, 2012). Additional research in this region will perhaps paint a more clear portrait.

It must also be acknowledged that different types of mills normally coexist in the same region or settlements, depending on a variety of reasons, such as the type of product to be ground, the social context or the urban or rural setting. There is no doubt that less expensive and more portable saddle querns were probably more common in households, whereas the Olynthus mills, as suggested by the Megarian bowl (Figure 3) illustrating a commercial flour mill, operated in business establishments (CURTIS, 2001, p. 284). For example, inhabitants in Roman Galilee (1st-2nd c. BC to the 1st-2nd c. AD) in a large town used Olynthus mills while in a small mountain village, in turn, they opted for saddle querns (MEYERS, 2011, p.246). In fact, in Israel at the end of the Roman period, saddle querns, Pompeian mills, Olynthus mills, rotary querns and watermills were all in use side by side. Likewise, Iberian rotary pushing mills are found both on large and small settlements, and they always coexist with rotary querns and saddle querns. They are found in some cases in specialised spaces which show a new organisation of production that was perhaps either extra-domestic (communal) or related to the larger dwellings of the elite. Maybe both domestic production and communal production coexisted.

The new grinding mechanisms from the middle of the 1st millennium BC were a turning point in the history of milling. At the end of this millennium another new and revolutionary type of mill, the watermill, appeared in the Mediterranean Basin. Although the origin and dating of both watermill types (horizontal and vertical water wheels) is not clear, they spread throughout the Mediterranean and beyond, initiating a new era of milling.

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Figures

Figure 1.- Schema of mill types and their means of operation in the Mediterranean Basin during the 1st millennium .

Figure 2.- Distribution of exceptional saddle quern types in the Mediterranean Basin during the 1st millennium BC (the mills represent zones, not sites; the datings represent the earliest examples of each zone): (a) Assyrian mills: (a.1.) Tel Tannim (AVSHALOM et al. 2004: fig. 1), (a.2.) Tell Barri (BOMBARDIERI 2010: fig. 92), 7th c. BC; (b) Archaic Greek type: Ullastret (PORTILLO 2006: 29.4), 4th c. BC; (c) Hand-grips type: Tossal del Moro de Pinyeres (ARTEAGA et al. 1990), 5th c. BC (d) Ribbed type: Cornia nou (PORTILLO et al. 2014: fig. 4), 4th-3rd c. BC; (e) Phoenician type (AVSHALOM et al. 2004: fig. 1); (f) Hand-grips type with hopper: Priene (MORITZ 1958, 43); (g) Hand-grips Olynthus mill: Thera (GAERTRINGEN, F.F.H. von, and WILSKI 1904: fig. 193).

Figure 3.- Ancient representations of the use of mills: (a) Greek figurines of women, 5th century BC, British Museum (NEILS 2011: 99); (b) Boeotian model (AMOURETTI 1986: planche 28); (c) fragment the side of a sarcophagus in the Vatican Museum (from AMELANG 1903 in PEACOCK 2013: fig. 5.7); (d) Megarian bowl found at Thebes (ROSTOVTZEFF 1937: fig. 1).




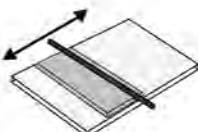


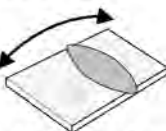


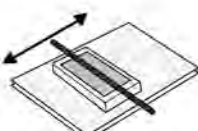


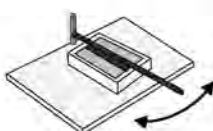


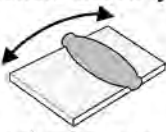


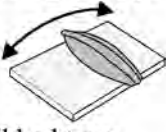


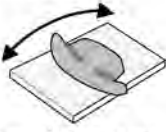


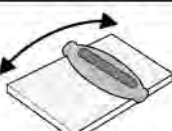


Figure 4.- Distribution of rotary querns (a) and Olynthus mills (b) in the Mediterranean Basin during the 1st millennium BC (the mills represent zones, not sites; the datings represent the earliest examples of each zone): (a.1) Els Vilars d'Arbeca, 5th c. BC (Catalonia); (a.2.) Alorda Park, 5th c. BC (Catalonia) (PORTILLO 2006: fig. 6.6); (a.3) Pech Maho, 5th c. BC (France) (PORTILLO 2006: 31.4); (a.4) Morgantina, 3rd c. BC (WHITE 1963: fig. 8); (a.5) La Bastida de les Alcusses (Valence, Spain), 3rd c. BC (BONET AND VIVES-FERRANDIZ 2011: fig.14); (a.6) Israel (FRANKEL 2003b: 54); (a.7) Priego de Córdoba; (a.8) Murcia; (a.9) Baelo Claudia; (a.10) Úbeda (all in Spain from the Roman period, ANDERSON 2013: fig. 3.6); (b.1) Tel Emq (Israel), type I1 (FRANKEL 2003a: fig. 16); (b.2.) Thassos (Greece), type I3 (AMOURETTI 1986: planche 23); (b.3) Lattara (France), type I12 (PY 1992: fig. 4); (b.4) Mast Hoyuk (BOMBARDIERI 2010: fig. 106.3); (b.5) Halleis (Greece), type I.1 (RUNNELS 1981); (b.5) Mast Hoyuk (BOMBARDIERI 2010: fig. 106.3); (b.6) reconstruction of the means of operating an Olynthus mill as at Gamla (FRANKEL 2003a: fig. 6); (b.7) reconstruction of the means of operating an Olynthus mill according to KOUROUNIOTES (1917, fig. 3).

Figure 5.- Distribution of Iberian rotatory push mills (a), Morgantina mills and Pompeian mills (b) in the Mediterranean Basin during the 1st millennium BC (the mills represent zones, not sites; the datings represent the earliest examples of each zone): (a.1) Els Vilars d'Arbeca, 6th c. BC (Catalonia); (a.2) Bastida de les Alcusses, 4th c. BC (Valence, Spain) (BONET AND VIVES-FERRANDIZ 2011: fig.14); (a.3) Tossal de Sant Miquel, 3rd c. BC (Valence, Spain) (photo H.Bonet); (a.4) Margalef, 3rd c. BC (ALONSO et al. in press: fig. 7); (a.5) operation of an Iberian rotatory pushing mill; (b.1) cross section of a Pompeian mill (left) and a Morgantina mill (WHITE 1963: fig. 10); (b.2) Morgantina mill from Morgantina (Sicily), 3rd c. BC (WHITE 1963: fig. 6); (b.3.) Pompeian mill from Ecija (Sevilla) (Sáez 1987: fig. 21); (b.4) mill from Hamworthy (England) (Bennet and Elton 1898: 183); (b.5) Pompeian mill from Etan Ayalon (Sur Natan, Israel) (FRANKEL 2003b: 55); (b.7) Pompeian mills in Pompeii (Italy) (PEACOCK 2013: fig. 5.3); (b.8) Pompeian mill from Ramdam Jamal, Algeria) (REINACH 1983 in PEACOCK 2013: fig. 5.8).

Figure 6.- Distribution of Iberian ring mills and Roman ring mills (a), Rotary olive edge roller (b) and segmented Delian mills (c) in the Mediterranean basin during the 1st millennium BC (the mills represent zones, not sites; the datings represent the earliest examples of each zone): (a.1) Horizontal ring oil mill (FRANKEL 1993: fig. 1); (a.2) Cerro de la Cruz, 2nd century BC (QUESADA et al. 2014: fig. 5); (a.3.) Volubilis (Peacock 2013: 5.13); (b.1) Delos (DEONNA 1983 in PEACOCK 2013: fig. 5.15); (b.2) reconstruction of a Delian mill by Storck and Teague (1952: fig. 40); (b.3) reconstruction of a Delian mill by Brunet (1997: fig. 3).

Figure 7.- (a) Watermills: (1) horizontal water wheel, (2) vertical water wheel; (b) geared mills: (1) driven manually, (2) driven by a donkey or horse (after Frankel 2003b).

Figure 8.- (a) Development and diffusion of the mills in the Mediterranean Basin during the first millennium BC (after FRANKEL 2007 modified); (b) Proportion of the different types of mills in the South of France, between the 5th and the 1st centuries BC (after JACCOTTEY et al. 2013: fig. 5).

TO-AND-FRO MOTION			Figure 1		
hand			lever		
<p>a. Saddle Quern</p> 			<p>g. Assyrian type</p> 		<p>groove</p> 
<p>b. Archaic Greek type</p> 			<p>hopper</p>  <p>straight movement</p>   <p>oscillating movement</p>    <p>h. Olynthus Mill</p>		
<p>c. Hand-grips type</p> 					
<p>d. Ribbed type</p> 					
<p>e. Phoenician type</p> 					
<p>f. Hand-grips with hopper</p> 		<p>hopper</p> 			

ROTARY MOTION













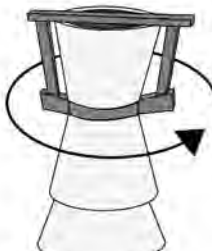


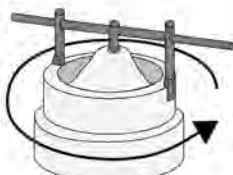


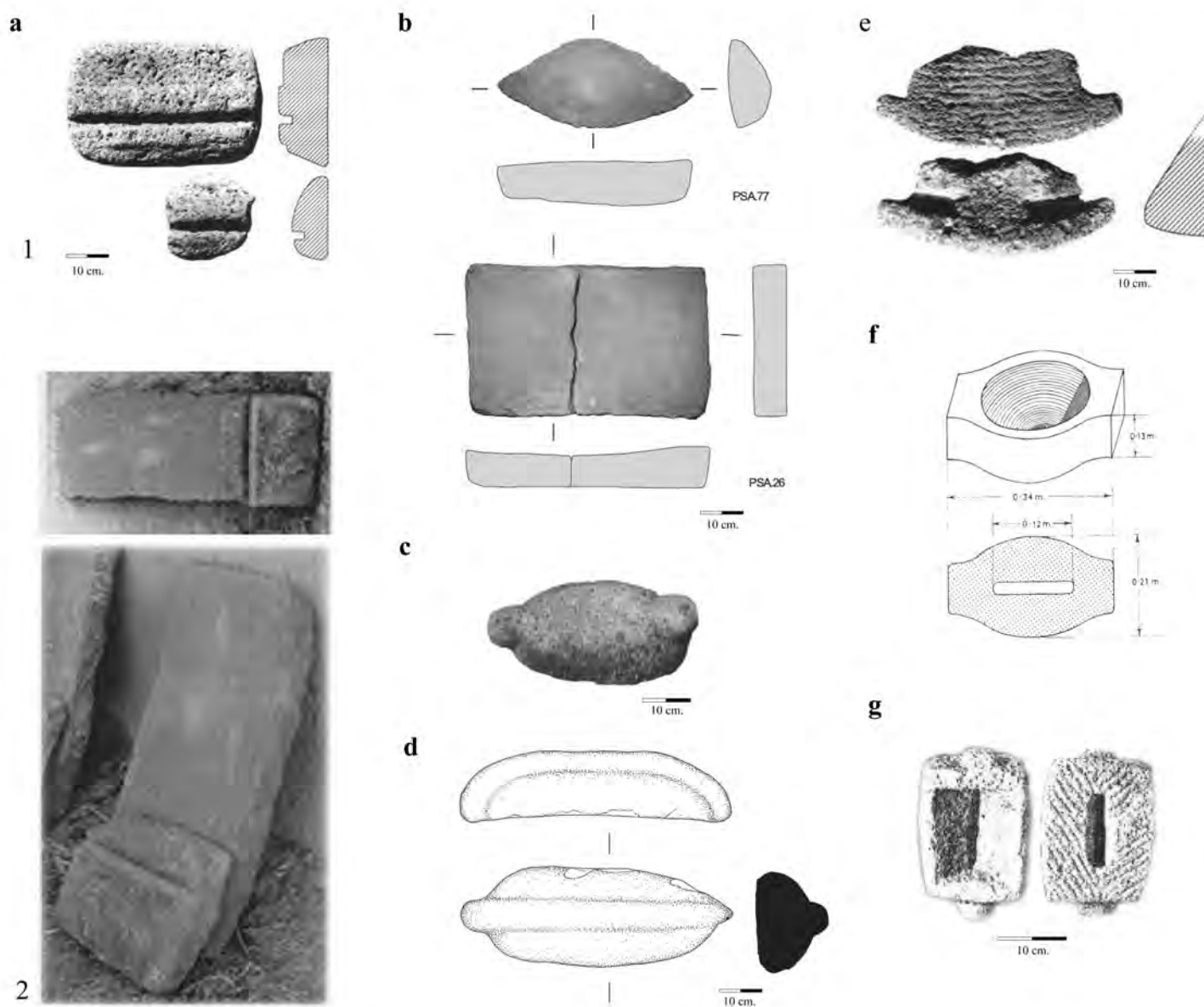
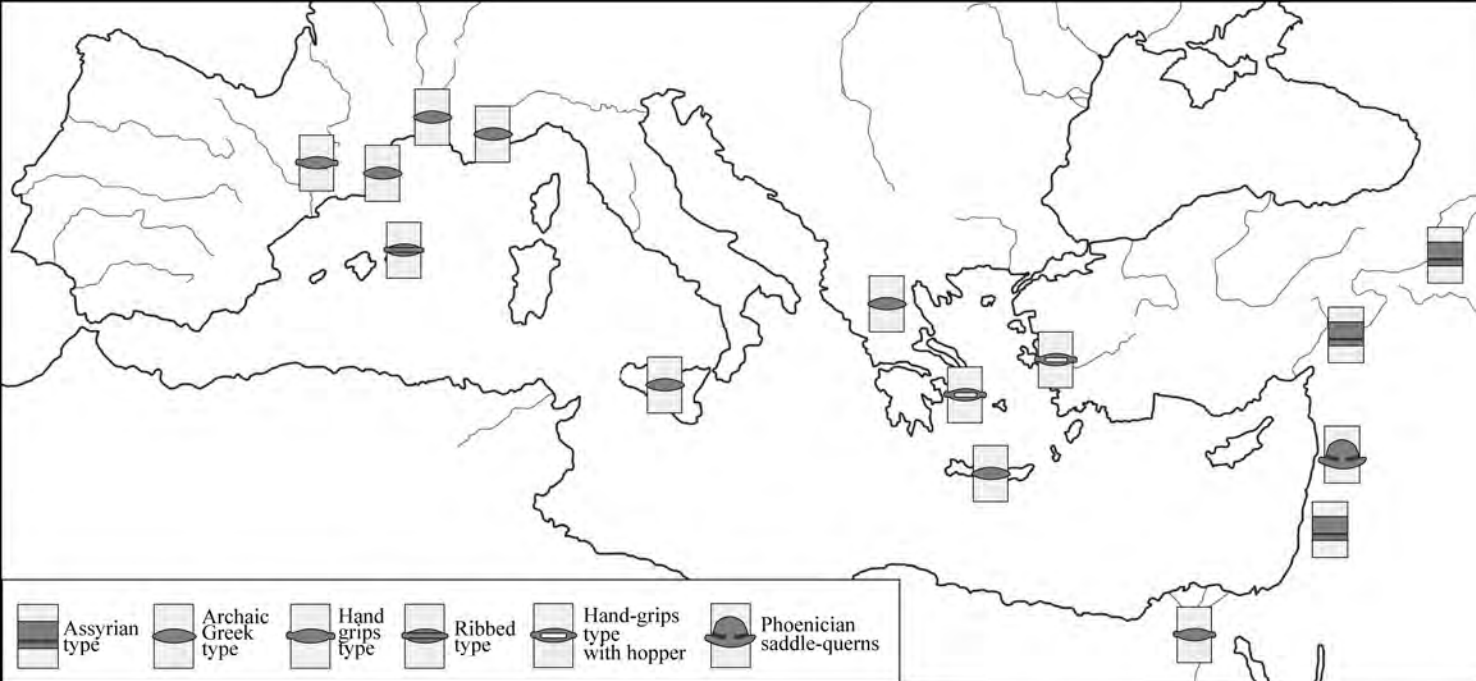
hand			lever		
 <p>semi-rotatory movement</p>			 <p>h. Iberian Rotatory Pushing Mill</p>		
 <p>rotatory movement</p> <p>h. Rotatory Hand Mill</p>			 <p>h. Morgantina Mill</p>		
			 <p>h. Pompeian Mill</p>		
			 <p>h. Ring Mill</p>		

Figure 2



a



b



Figure 3



c



d

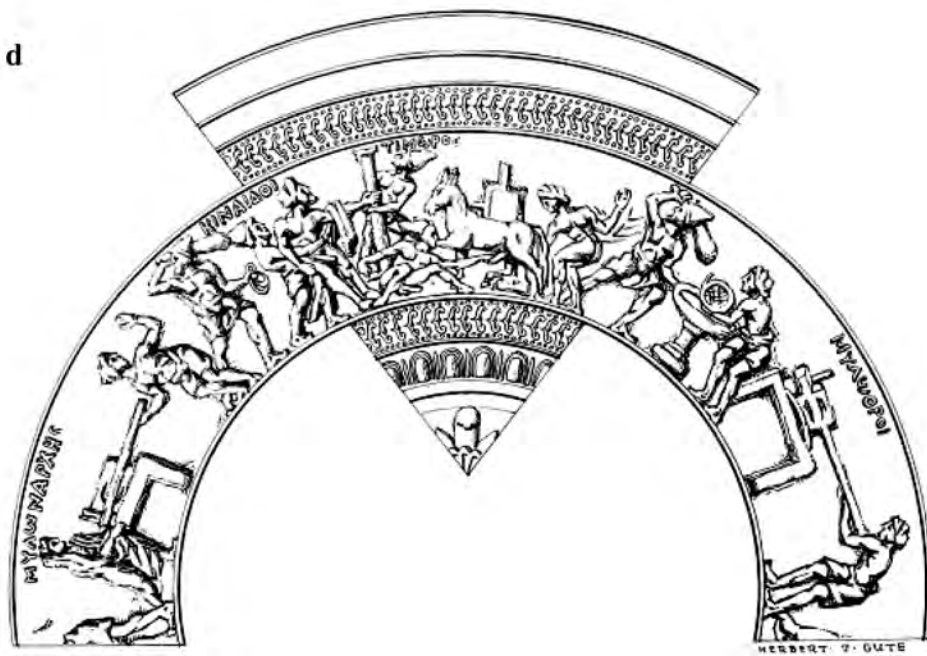


Figure 4

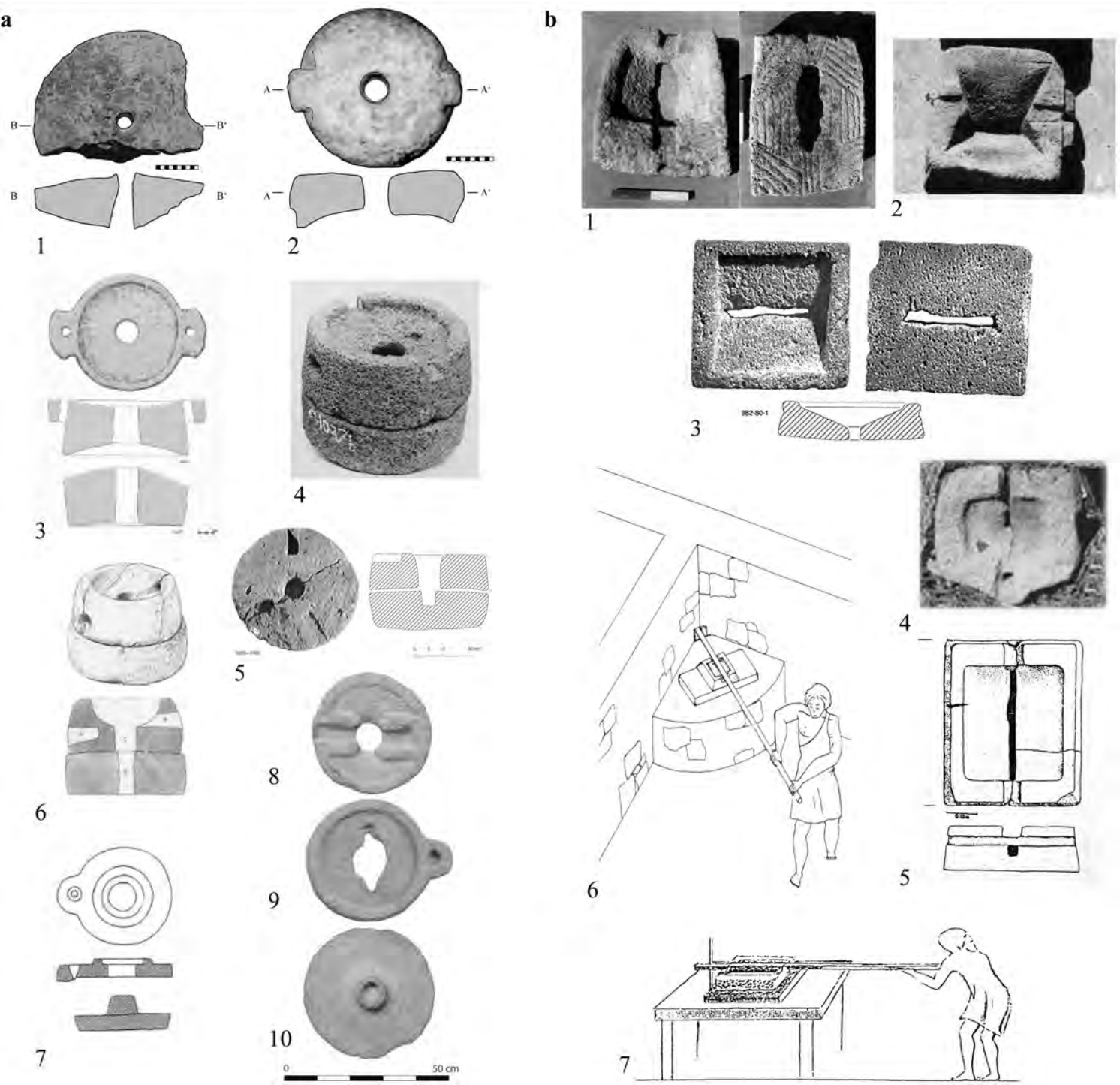
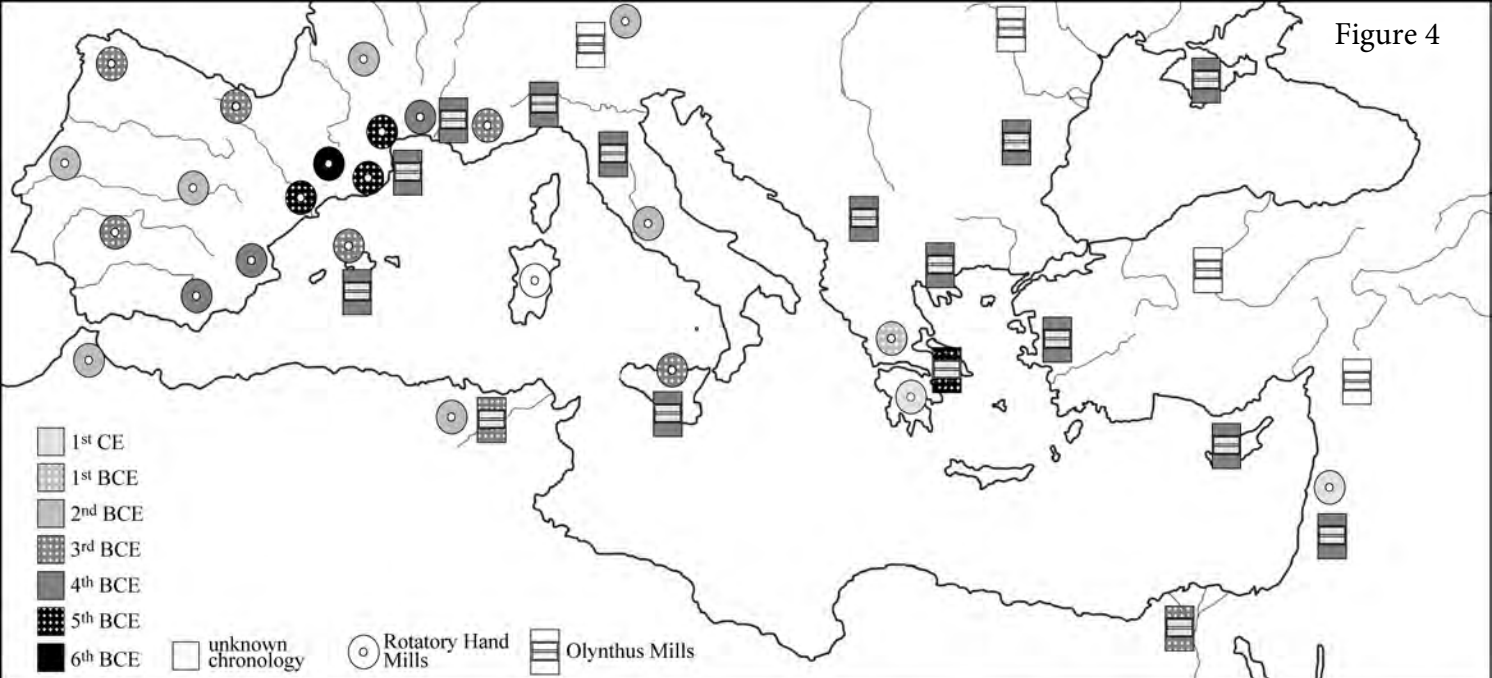


Figure 5

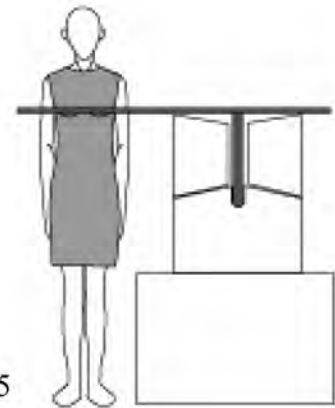
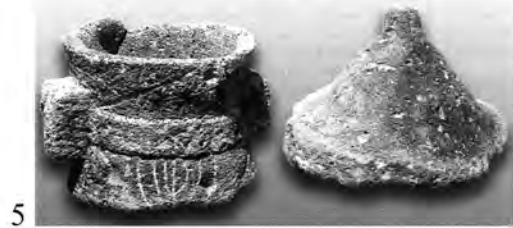
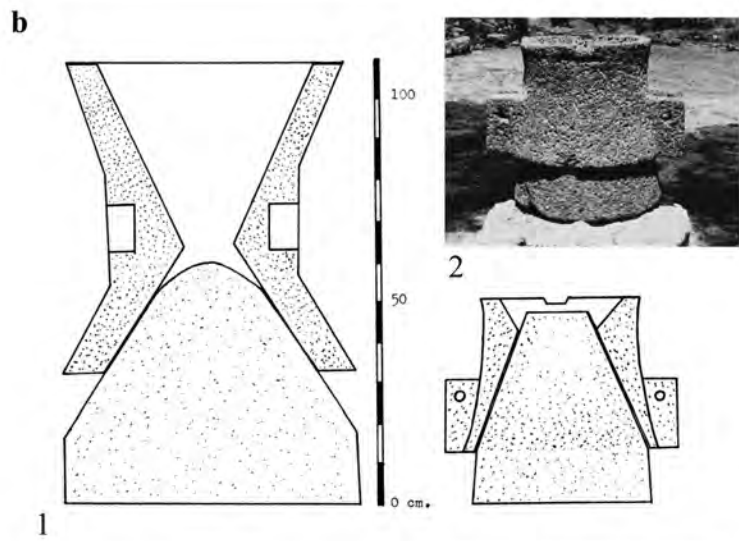
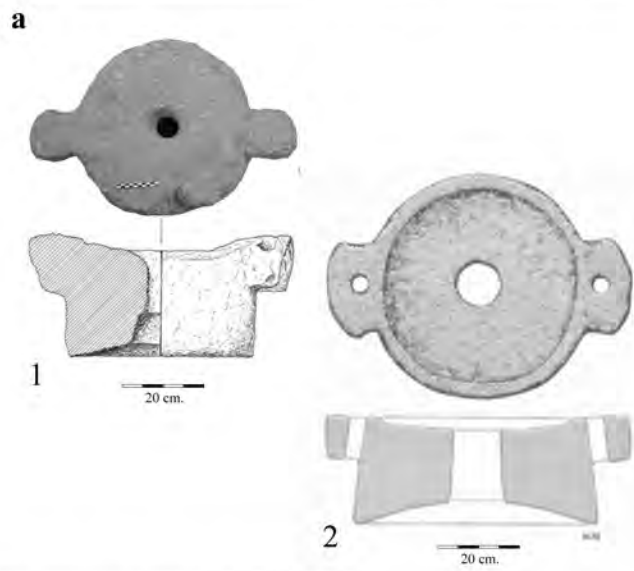
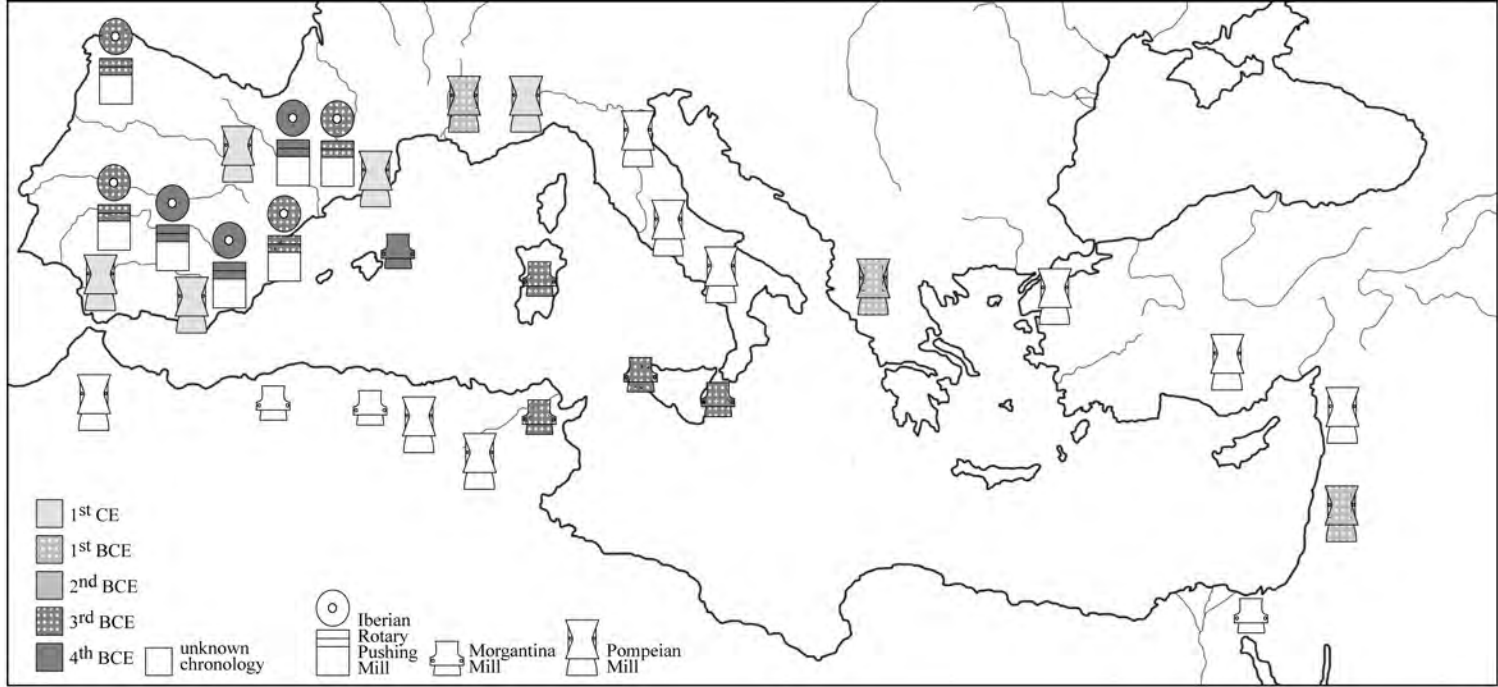
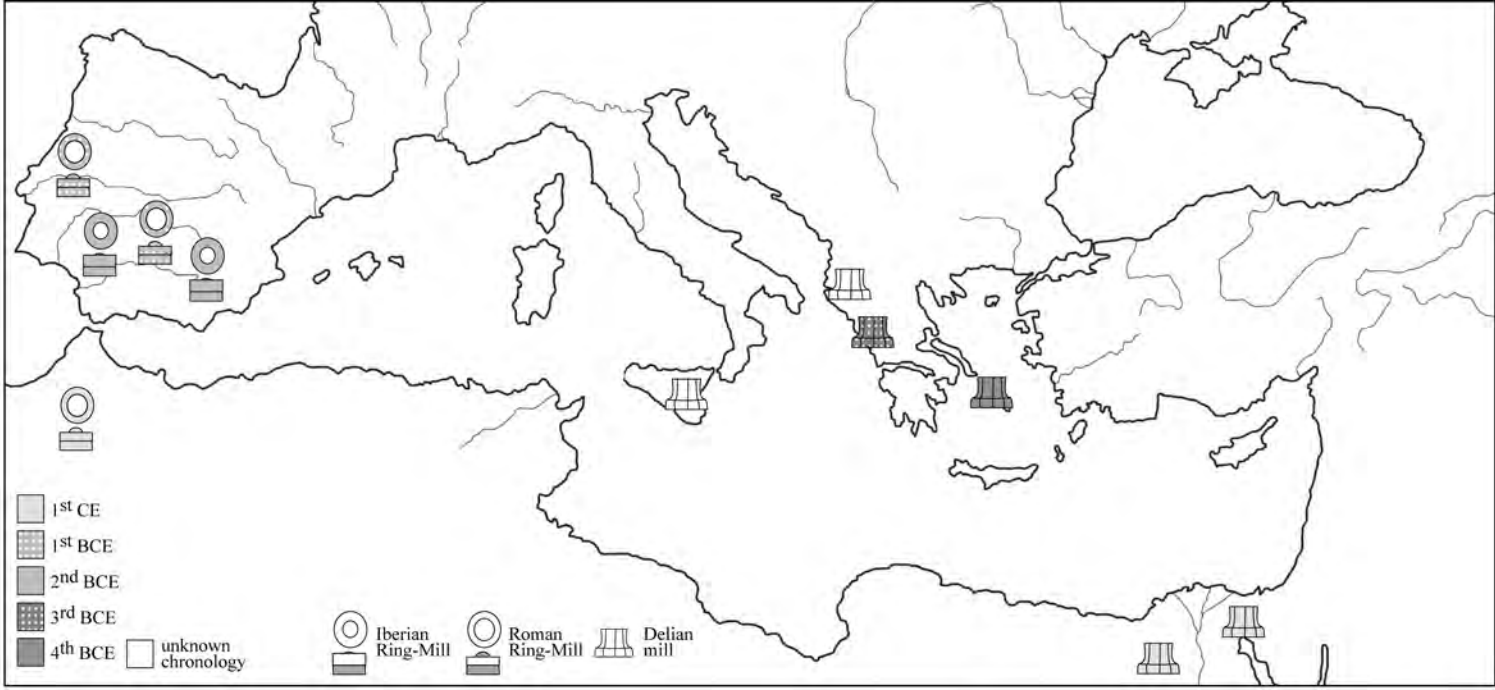
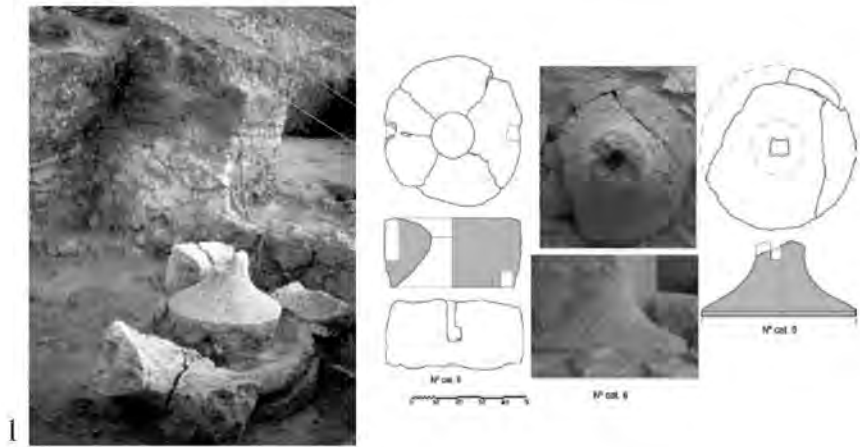


Figure 6



a



b

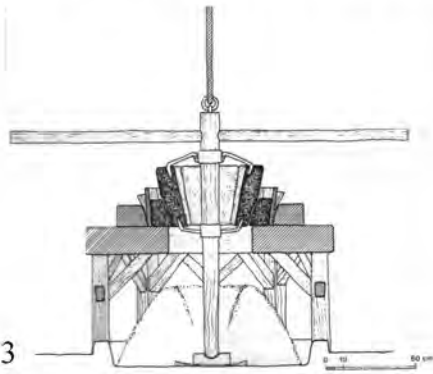
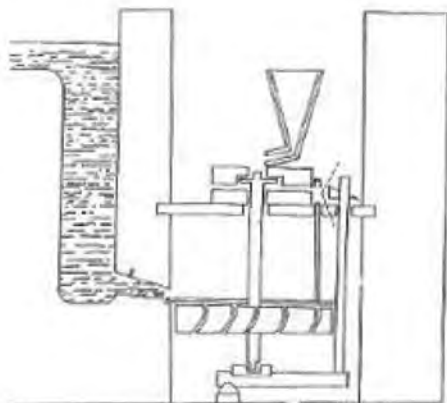
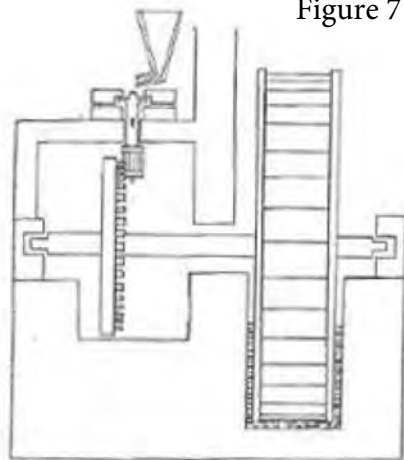


Figure 7

a

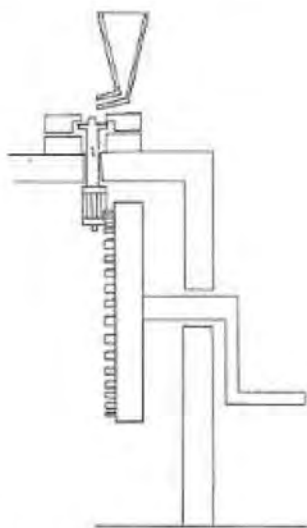


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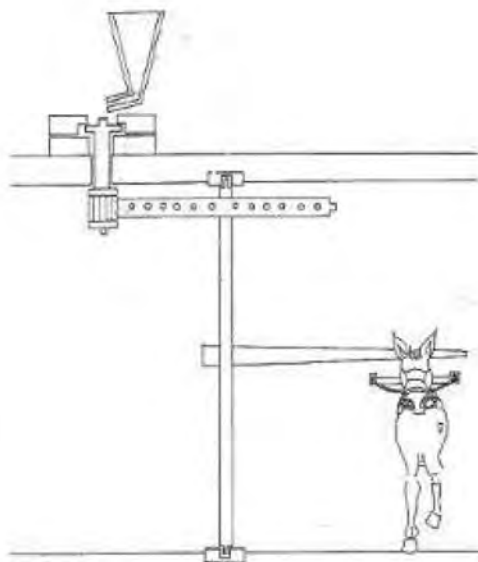


2

b



1



2

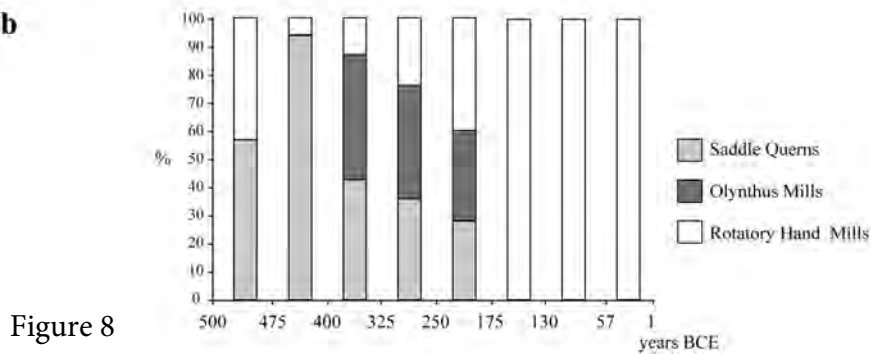
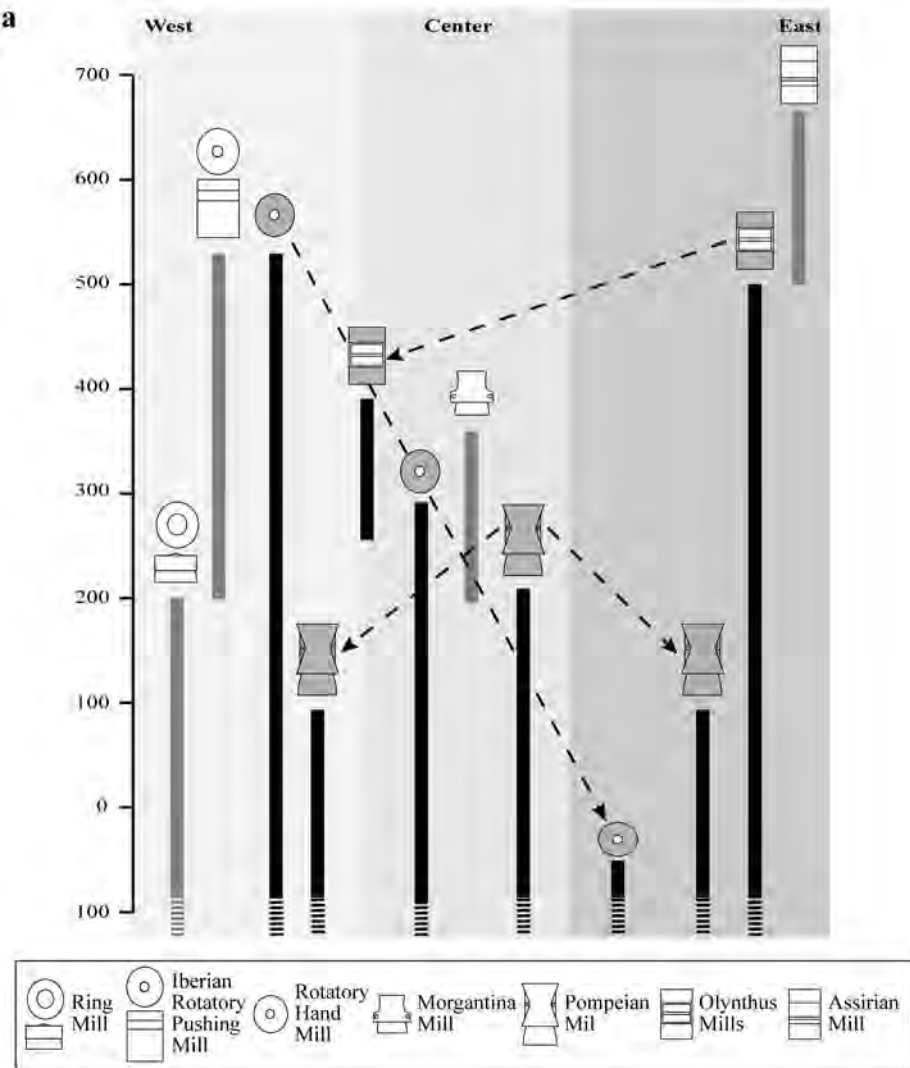


Figure 8